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DEVELOPMENT OF THE PHYSIOGRAPHY OF THE WESTERN HIGHLAND RIM PLATEAU IN TENNESSEE BY GROUND-WATER SAPPING OR REJUVENATED STREAM CYCLE

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ABSTRACT

In this area there is close similarity in pattern of: configuration of the upland, structure of base of Cretaceous, and erosional levels of graded streams. Two alternative causal connections are likely: (1) more recent steep-sided valleys are incised in old wide gentle valleys cut before Middle Cretaceous time by the same streams; (2) (preferred) the stream flow system extends its erosional influence beneath the rim, and the insloping surface of the old upland (capped by Cretaceous outliers) sags toward the incised streams because of ground-water sapping. An unlikely third possibility is that streams flow in synclines folded after development of the upland.

In order to compare upland levels, bottomland levels, and Cretaceous structure (each having different density of basic information) the "envelope" and "subenvelope" are developed. These are arbitrarily generalized reproducible contour maps. The envelope is a surface over the topography that graphically "fills in" valleys and sags. It does not average topography but limits it on the high side. It is here regarded as an attempt to restore the topography to an hypothetical earlier stage before the valleys were incised. The subenvelope is a surface passing beneath the land surface, graphically "tearing away" hills. It limits topography on the low side. It may be regarded in this case as an attempt to predict topography that may develop if the stream system continues a long time at its present grade.

Parallelism of contours developed by these techniques is consistent with either ground-water sapping or a rejuvenated stream cycle, but the 70 million (or so) years since the upland was developed seems to be an excessive time for the supposed new stream peneplain to be so little developed. This set of relationships casts doubt on the notion that the relatively even Highland Rim surface is a stream-developed peneplain.

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DEVELOPMENT OF THE PHYSIOGRAPHY OF THE WESTERN HIGHLAND RIM PLATEAU IN TENNESSEE BY GROUND-WATER SAPPING OR REJUVENATED STREAM CYCLE

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INTRODUCTION

This report describes selected aspects of the geology and physiography of the region, mainly by means of generalized contour maps, or "envelopes," and presents views as to the origin of interrelated stream pattern, land shape, and geologic features.

Study of erosional physiography is generally unsatisfactory to the historical geologist because erosional features commonly cannot be dated with confidence. In this case, however, basal Cretaceous gravel outliers are scattered across the upland surface, so it can be stated with confidence that the upland surface was eroded to about its present form and probably was a relatively flat surface (peneplain) in pre-Upper Cretaceous time (Marcher and Stearns, 1962). The valley bottoms are being eroded today. Because of the evident great span of geologic time (+70 million years) the Western Highland Rim is a favorable case to study the development of both physiography and epeirogenic structural form. Here we can examine the lengthy process of development of a peneplain by achievement of equilibrium erosion levels in the modern stream system (base leveling) in the original sense of Powell (1875, p. 203). Also, we can inquire into the structural bending of the old surface during the same time.

The writer wishes to acknowledge the assistance of the Tennessee Division of Geology, the Tennessee Valley Aurhority, and the National Aeronautics and

Space Administration. In the early stages of the project the writer was employed by the Tennessee Division of Geology and received technical assistance from the Tennessee Valley Authority. Later stages of the work were supported by a grant from the National Aeronautics and Space Administration, as part of a current project of the Department of Geology at Vanderbilt University, to study the relationship of the Wells Creek cryptoexplosive structure (in the northern part of the area) to the Highland Rim surface (NASA Grant NSG 465). Some of the conclusions were discussed with C. W. Wilson, Jr., of Vanderbilt University, Melvin V. Marcher of the Ground-Water Branch, U. S. Geological Survey, and Phyllis S. Marsh, Geologist, of Vanderbilt University. Robert A. Miller, Senior Geologist, Tennessee Division of Geology, edited and designed the drawings. Robert J. Floyd, Principal Geologist, Tennessee Division of Geology, edited the manuscript.

GENERAL PHYSIOGRAPHY

The Western Highland Rim is the upland physiographic province of Middle Tennessee located between the Central Basin on the east and the Mississippi Embayment on the west (Figs. 1 and 2). The surface formations throughout most of the area are Mississippian limestones--mostly Forty Payne Formation in the south, and the next overlying Warsaw and St. Louis Limestones to the north (Fig. 3). Stream erosion has exposed Devonian, Silurian, and Ordovician formations in some of the valleys, and isolated remnants of the Tuscaloosa Gravel of Cretaceous age cap part of the upland surface (Marcher and Stearns, 1962).

The Western Highland Rim exhibits many aspects of the classic stream erosion cycle, but two principal stages are the basis for this study. There is the old upland surface, nearly flat in skyline view, which can, for purposes of this paper and without certainty as to its actual origin, be considered a "peneplain." Steep-sided valleys have been incised as much as 400 feet. Along main streams these sharp valleys have well-developed bottom lands, which, for purposes of this paper, may be regarded as the start of a new peneplain.

Figure 4 shows the distribution of upland and bottomland areas. In the areas colored black the upland surface has been almost completely destroyed by erosion and much of this area is flood plain. The white area is mostly upland surface, because the slopes from the upland to the bottomland areas are quite steep and occupy only a small area.

THE "ENVELOPE" METHOD OF COMPARISON

Purpose of the Envelope

Generalized contour maps, or "envelopes," (Fig. 5) will be used in an attempt to reconstruct the shape of the ancient upland surface, to predict the shape of the new peneplain now being formed, and to suggest the causal connection between the erosion pattern of graded streams and the configuration of the ancient upland surface. The actual upland surface is well approximated on a scale of 1/24,000 (2,000 feet to the inch) on published topographic maps. On these maps, however, details of contour pattern are emphasized and generalities are masked. The "envelope" device is a means of consistently generalizing selected aspects of topographic contours. It has the advantage of consistency and reproducibility, and shows, in an easily-seen generalized contour form, features of the physiography that ordinarily require either time-consuming travel to many scenic vantage points or nerve-wracking attention to a mass of detail on many topographic maps.

Properties of the Envelope and Subenvelope

An envelope is defined by Websters Unabridged Dictionary (1952) as "That which envelopes; Geometrically it is the locus of intersections of a family of. . . surfaces . . . tangent to each element; thus any curve (or surface) is the envelope of its tangent lines (or planes)." For purposes of this paper the envelope is a surface enveloping the actual topography, touching (tangent to) the land surface at high spots, never passing below ground; nearly everywhere a short distance in the air, and a greater distance in the air across valleys.

It is essential, once the above restrictions are observed, only to specify how wide a low spot can be crossed without the envelope itself lowering. The envelope must be described, for example, as a 2,000-foot envelope, meaning that it can "jump across" or "fill in" valleys or low spots as wide as 2,000 feet. Other intervals can be used. These limit the complexity of contour lines whose sinuous curves must have a curve length greater than the length limit arbitrarily imposed. The topographic envelope, therefore, is an arbitrarily generalized contour map representing a surface smoother than the actual topography, graphically filling in the valleys and sags. It is important to understand that it does not "average" topography but limits topography on the "high side" (Fig. 5a).

The subenvelope is the reverse of the envelope. It is tangent to valley bottoms and bottoms of low spots. It is never in the air. In valleys it is at or a short distance below ground level. It is deep underground only where it crosses hills. It is again essential to specify how wide a hill can be "crossed under" without the subenvelope surface rising. The topographic subenvelope, therefore, is an arbitrarily generalized contour map representing a surface smoother than the actual topography, graphically tearing away the hills. Again it is important to bear in mind that it does not average topography but limits it on the "low side" (Fig. 5b).

If we are dealing with peneplains, then the envelope can be regarded as a (partial at least) restoration of the earlier more complete peneplain of the past; the subenvelope may be regarded inversely as a prediction of the approximate shape of the peneplain to be developed in the future if present conditions continue for a geologically long time.

The subenvelope also may be regarded as an actual map of the erosional portion of that heretofore elusive and imaginary surface called "base level" (Powell, 1875; and Barrell, 1917), particularly when spacings are such that substantial flood plains control the pattern. Although it may strain the patience of some readers, it is well to add that the base level mentioned here is not the flat sea level base of Davis (1902) but is the gradient-controlled and therefore sloping base level in its original physiographic definition, and in its operational definition from the viewpoint of the stratigrapher (e.g., Wheeler and Murray, 1957, who considered both inland erosion and coastal plain and marine deposition).

Construction of an Envelope

Figure 6 shows a portion of the Tennessee Valley Authority topographic map 30-SW, McEwen, Tennessee. The original solid contour lines are generalized to a 2,000-foot envelope, shown as heavy lines, by drawing the heavy lines tangent to the outcurving convex side of the contour line. Note that the envelope takes shape nicely with little opportunity for variation in trend of envelope contours, that is to say it is not interpretive. One must be careful at this stage, however, to mark outlying small hills for further reference, because when more generalized (longer spacing) envelopes are made from these, such outliers should control contour lines.

In this manner an envelope or subenvelope for any isopleth map may be constructed. In this report the technique also will be used to construct generalized structure maps for direct comparison with topographic envelopes.

TYPES OF MAPS TO BE COMPARED

The configuration of upland, bottomland, and the base of the Cretaceous will be compared. Upland is described by means of envelopes, bottomland by subenvelopes, and the Cretaceous base by structure contour maps. The problem is mainly one of manipulating the available information so that the various components can be compared at the same map scale and same degree of generalization (spacing).

Upland surface control points easily can be obtained on a 2,000-foot spacing (as on Fig. 6) or even less. However, this detail has no utility for comparison of the upland with the base of the Cretaceous, because Cretaceous outliers average about 2 miles apart. The minimum spacing for envelopes therefore must be 2 miles if they are to be compared with the Cretaceous structure.

Bottomland maps on a 2-mile spacing must use as control in most places the beds of small streams with no bottomland; these are probably not at grade. Streams with substantial floodplains (the ones most apt to be at grade) are spaced about 6 miles apart. These are the basis for the 6-mile bottomland subenvelope, which shows the surface that is now being created by the graded streams (erosional base level). Upland and base of Cretaceous both must be generalized to the 6-mile envelopes if any comparison with the bottomland 6-mile subenvelope is to be meaningful. Note here that the structural contour map is converted to an envelope by a technique identical to that shown on Fig. 6.

A 10-mile envelope also is drawn in an attempt to remove all effects attributable to local stream patterns. It can only show irregularities wider than 10 miles.

STRUCTURE, UPLAND, AND BOTTOMLAND COMPARED ON A 2-MILE SPACING

Figure 7a is a structure contour map on the base of the Cretaceous, which consists of outliers scattered across the Highland Rim surface. Control points are on an average spacing of 2 miles. It can be seen that the configuration of the base of the Cretaceous (Fig. 7a) is similar to that of the old upland surface

(Fig. 7b). The northward-trending contours to the west are along the edge of the Mississippi Embayment. The sinuous course of the contours on the Rim coincides with stream valleys. The Cumberland River flows through the 600-foot depression to the north, and the Duck River cuts across the 700-foot contour near the center.

Figure 7b is a generalized contour map or "envelope" showing configuration of the upland surface. This particular "envelope" describes a surface smoothed so that it touches the land surface at high points no more than 2 miles apart; nowhere does it go below the ground surface. Because the upland surface is nearly flat, the envelope generally is not more than 20 feet in the air, except over valleys where it is 200 to 400 feet in the air. The 2-mile spacing was chosen so as to compare physiography with the 2-mile spacing of remnants of the Cretaceous.

Actually, this envelope is a graphic "filling-up" of all valleys less than 2 miles wide, in an attempt to restore the configuration of the ancient upland surface. Irregularities on the map are truly irregularities of the upland surface, not the valleys.

It is significant to observe that the envelope contour lines (which are generalizations of more complex lines on the actual upland surface), curve to fit the positions of the main stream valleys, as on the contour map of the base of the Cretaceous (Fig. 7a). This relationship may be interpreted in three ways: (1) present streams occupy narrow deep valleys incised within broad valleys cut by ancient streams; (2) the ancient upland surface once had a different shape but has since been tectonically bent, and the present main streams are consequent and flow in post-Cretaceous synclines (unlikely pattern as has been suggested by White, 1960 who worked with Devonian structure in the Waynesboro quadrangle in the southeast part of the Rim); and (3) the (tentatively preferred interpretation in agreement with White, 1960 , that the upland surface, once flatter than it is now and covered with Cretaceous gravel, has sagged toward the main stream valleys because of subsurface sapping of soluble limestone by ground water to a greater degree along main stream valleys.

Figure 7c is a "subenvelope" of the bottomland. In effect, it is the reverse of the upland 2-mile "envelope." The surface has been smoothed so that it touches the valley bottoms at low points no more than 2 miles apart; elsewhere, it is underground.

This is a graphic "tearing away" of all hills less than 2 miles wide. It is an effort to predict the generalized shape of the future peneplain that might form if the smaller order streams keep widening their flood plains, and their tributaries continue eroding away the upland and grading it toward the main streams. This map is similar in pattern to the others, and suggests that even small streams that occupy steep v-shaped valleys may be close to grade.

STRUCTURE, UPLAND, AND BOTTOMLAND COMPARED AT A 6-MILE SPACING

Figure 8a is a structure map of the base of the Cretaceous on a 6-mile spacing. Figure 8b is an upland "envelope" on a 6-mile spacing; that is, it touches the land surface at points no farther apart than 6 miles. Figure 8c is a bottomland "subenvelope" on a 6-mile spacing. It represents an approximation of the new land surface presently being made by stream erosion of the larger streams with lowest gradients and significant bottomland areas. It is drawn at the smallest spacing that nearly everywhere uses flood plains as control. The similarity of all three maps is striking.

On Figure 8a, structure of the Cretaceous base on a 6-mile spacing, the regional structural pattern is well displayed. If the stream valleys are structurally controlled, the map may be an overgeneralization. But if the old upland sags toward streams by ground-water sapping, the map is a valid attempt to restore structure by allowing for sapping along belts narrower than 6 miles. Some contour irregularity still shows along the main stream courses, but the pattern of bulging of the Cretaceous as a part of the post-Cretaceous growth of the Nashville Dome (Wilson and Stearns, 1962) is well displayed. The southern part of the map is the southwestern extension of the Nashville Dome.

The bottomland 6-mile "subenvelope" (Fig. 8c) is a general wormseye view of the drainage basins and also perhaps an approximation of the peneplain that might develop if stream erosion proceeded uninterrupted for an extremely long time in the absence of significant structural movement. This is the closest spacing that permits use nearly everywhere of flood plain levels of graded streams to describe base-level. Similarity of this map to the 6-mile upland map is consistent with the hypothesis that the old upland is a stream-developed peneplain with the same streams trenched about 200 feet to form the new cycle. Here we have a new surface being formed with a shape very similar to that of an old upland surface of unknown origin. It is, of course, also consistent with the alternate hypotheses of structural control or ground-water sapping.

10-MILE UPLAND "ENVELOPE"

Figure 9 is an upland "envelope" on a 10-mile spacing. This was drawn to remove all likely stream coincident (and other small) irregularities. This map shows the epeirogenic structural configuration of the upland surface without any irregularities less than 10 miles wide. One major trough more than 10 miles wide still remains in the center of the area, along the Duck River valley. This can be explained as being a very broad ancestral Duck River, as a true wide structural syncline, or as a broad subsidiary belt caused by very broad subsurface sapping by ground water.

POSSIBLE EFFECT OF SUBSURFACE SAPPING

By subtracting the upland 2-mile "envelope" from (that of) the upland 10-mile "envelope," we obtain the data to construct Fig. 10. This map similarly may be interpreted in three ways. It may be considered to represent the pattern of ancient valleys on the old peneplain; that is, gently sloping valleys 2 to 6 miles side with a relief of only about 150 feet (hypothesis supported by similarity of envelope and subenvelope). Or, the map may suggest the structural features that control stream patterns; some structural grain is suggested, as the east-west lineation in the southern part of the area and the north-south grain in the central part (hypothesis appears unlikely because pattern is mainly that of dendritic streams as suggested by White, 1960). The third (believed to be most likely) possibility is that this is an isopach map of the material removed by ground-water sapping. It would appear that material has been sapped away in belts 4 to 5 miles wide on both sides of deeply incised streams, and that the average amount of sapping is about 100 feet. The material is believed to have been carried away from beneath the surface of the Highland Rim by solution or suspension of sediments in underground streams tributary to the surface streams.

SUMMARY

One basic relationship is obvious from this study; there is a close similarity in pattern of the configuration of the upland, the base of the Cretaceous, and the erosional tendency of graded streams. The main problem is to determine the connection in the relationship between the main streams and the insloping Rim surface with its scattered Cretaceous gravels.

Three possibilities are suggested: (1) the valley systems themselves are very old, and the more recent steep-sided valleys have been incised in old wide gentle valleys cut by the same streams; (2) (less likely) the streams flow in synclines folded after development of the upland, which once had a different shape; (3) (preferred) the stream flow system extends its erosional influence beneath the Rim, and the insloping surface along the valleys is largely the result of ground-water sapping. The last alternative is preferred but has not been proved conclusively. Proof must await studies of rates of erosion in this region by both solution and mass wasting.

Looking at this investigation and paper in retrospect, the writer is struck by the doubtful nature of the ultimate relationships in even this rather ideal case. The historical geologist, in dealing with erosional history, is concerned with a destructive process that leaves less and less record. We are still left in doubt as to the actual origin of the upland surface. The writer also is aware that even though the equilibrium base-level of the erosional process in this region can be drawn, in 70 million years only a small percentage of this area actually has achieved this base level. Thus the writer is left in the sad plight of doubting the reality of stream-created peneplains, even though he used the concept as an operational device to create reproducible maps.

These doubts are, however, not destructive to the preferred conclusion of this paper, that is, subsurface sapping of the upland by the stream pattern. Rather, it casts doubt on the origin of the upland by stream erosion. This doubt serves to reinforce the writers' belief in the ground-water sapping hypothesis.

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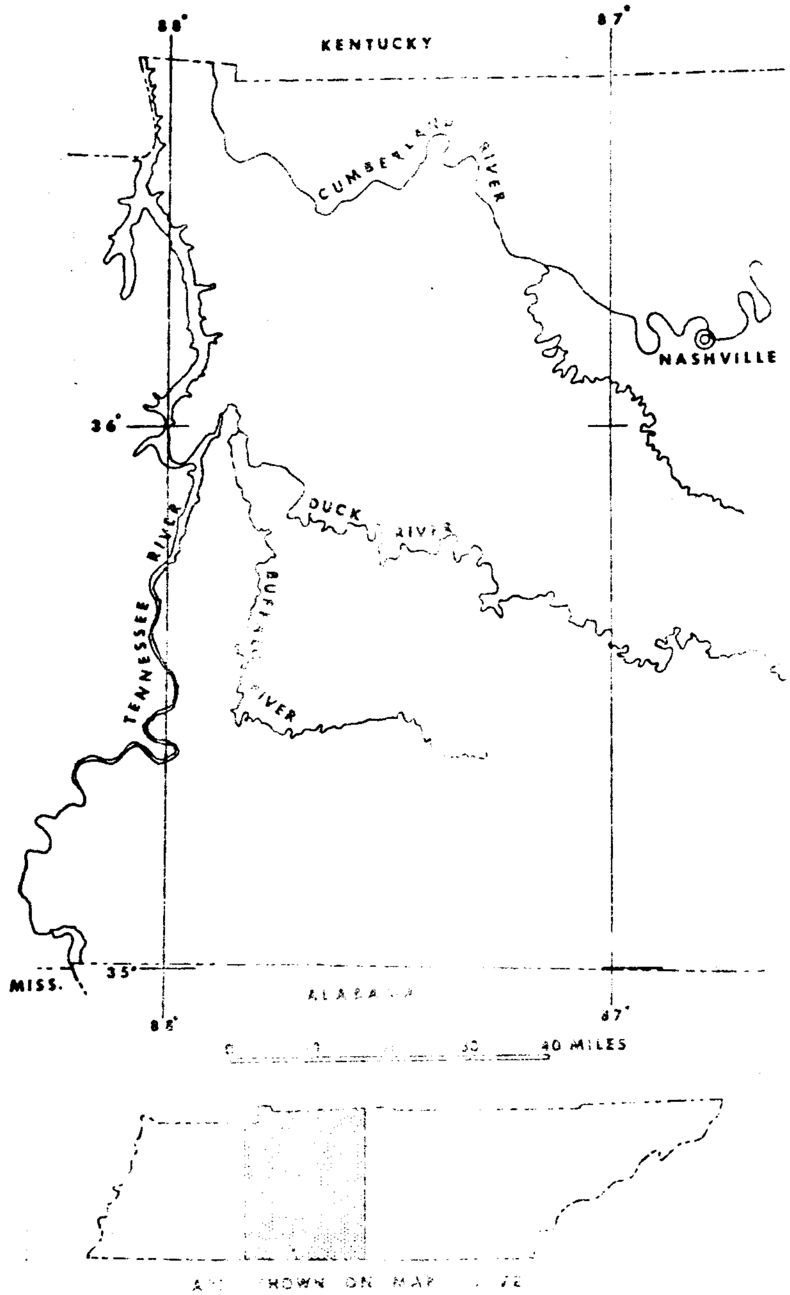

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Figure 1-

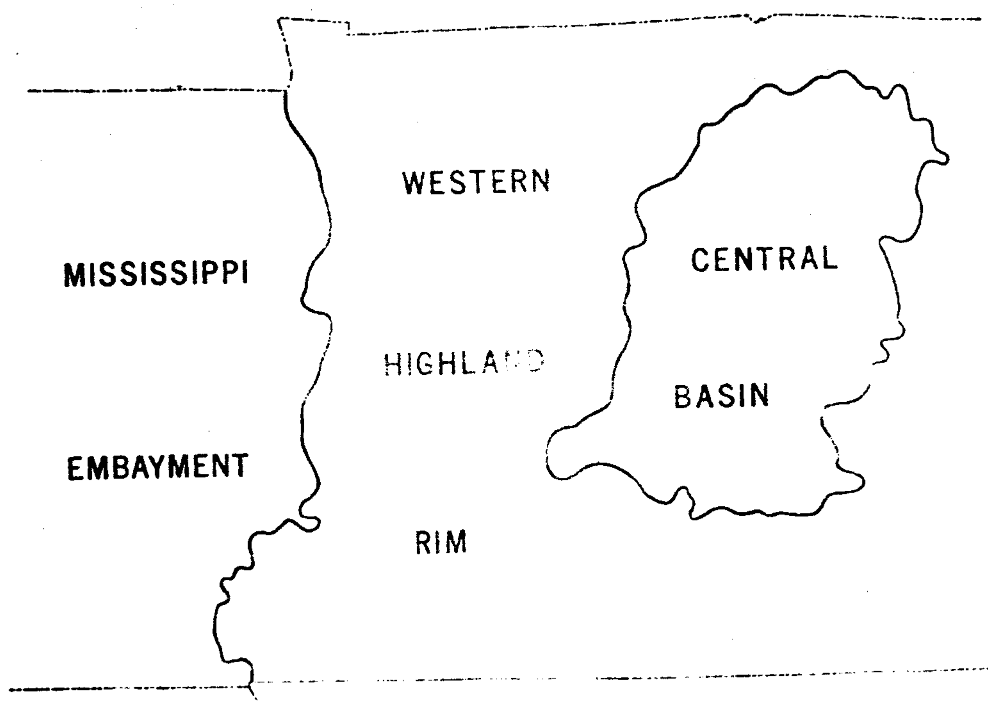


Figure [illegible] Western Highland Rim [illegible]ces.

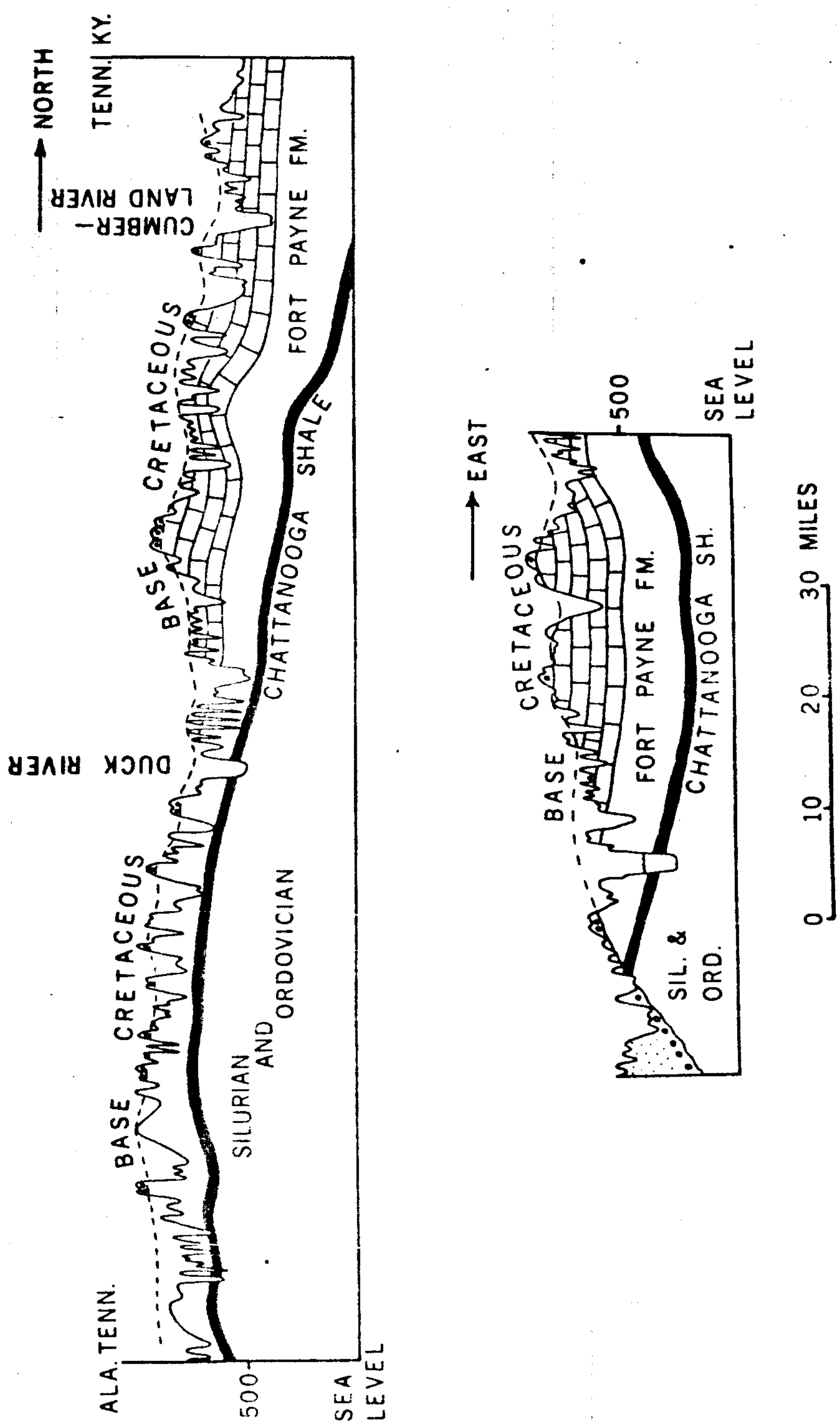


Figure 3- Geologic cross sections of the Western Highland Rim.

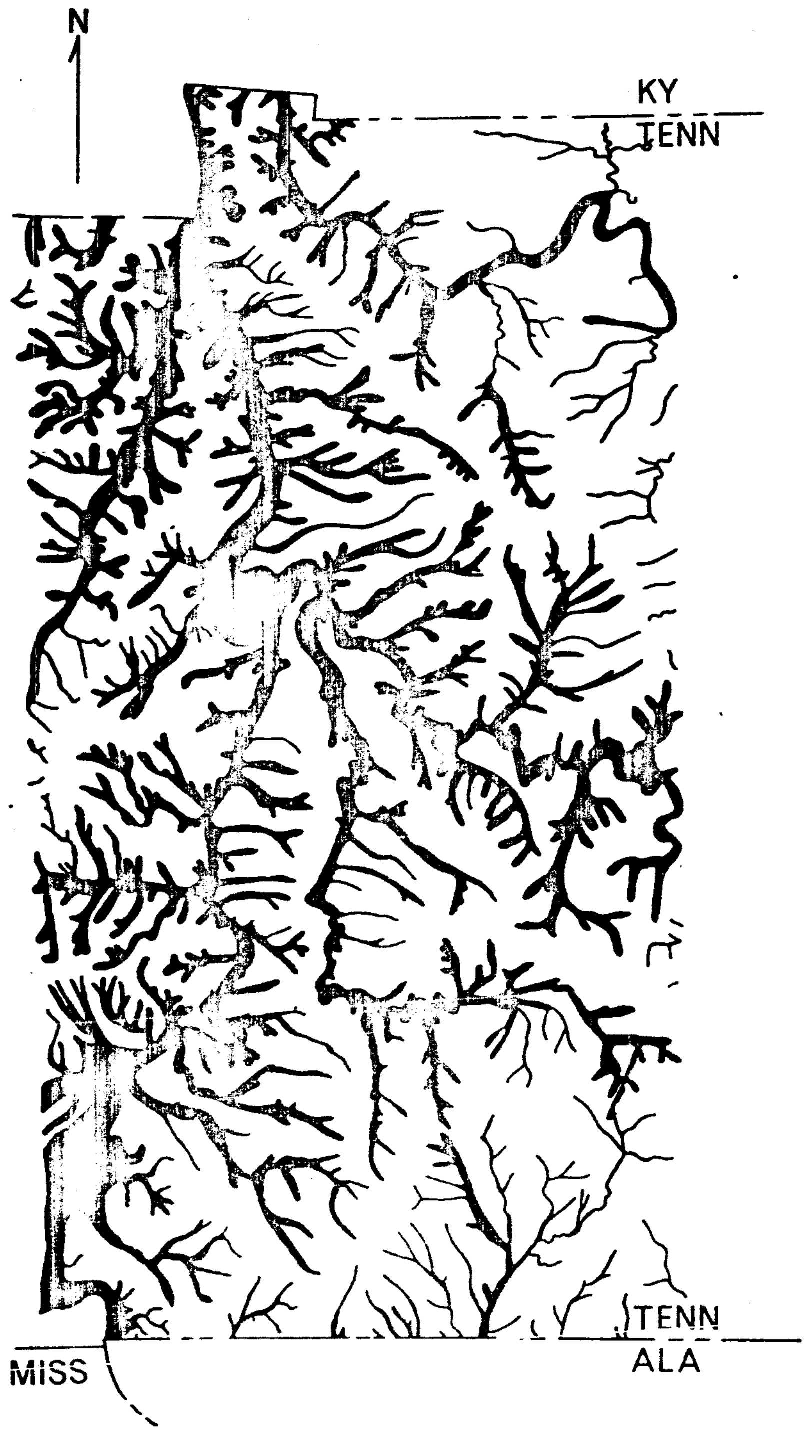


Figure 4- Distribution of upland (white) and bottomland (black) areas.

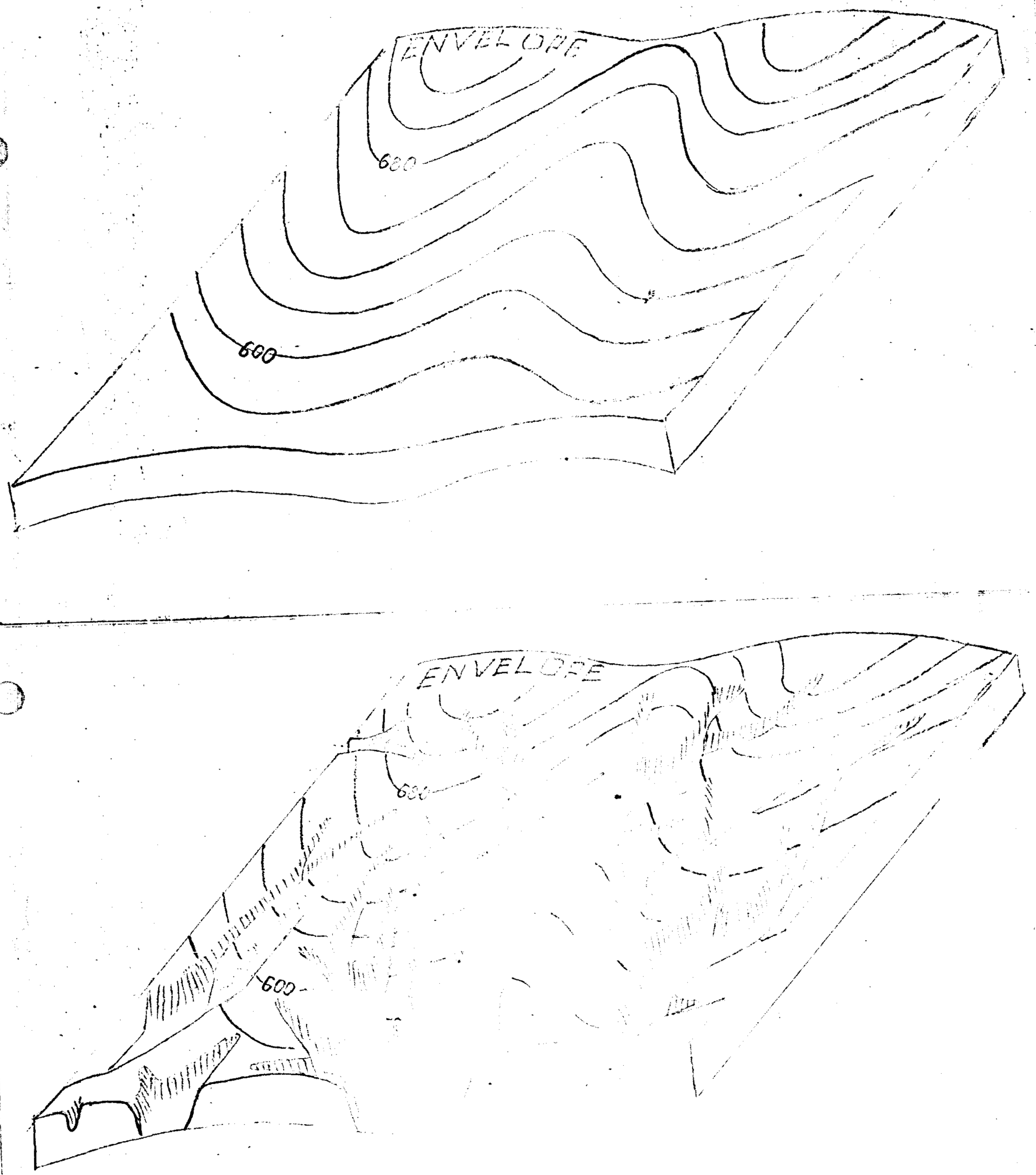


Figure 5a- The concept of an envelope. The top figure is the envelope. The lower figure shows its relation to the upland surface.

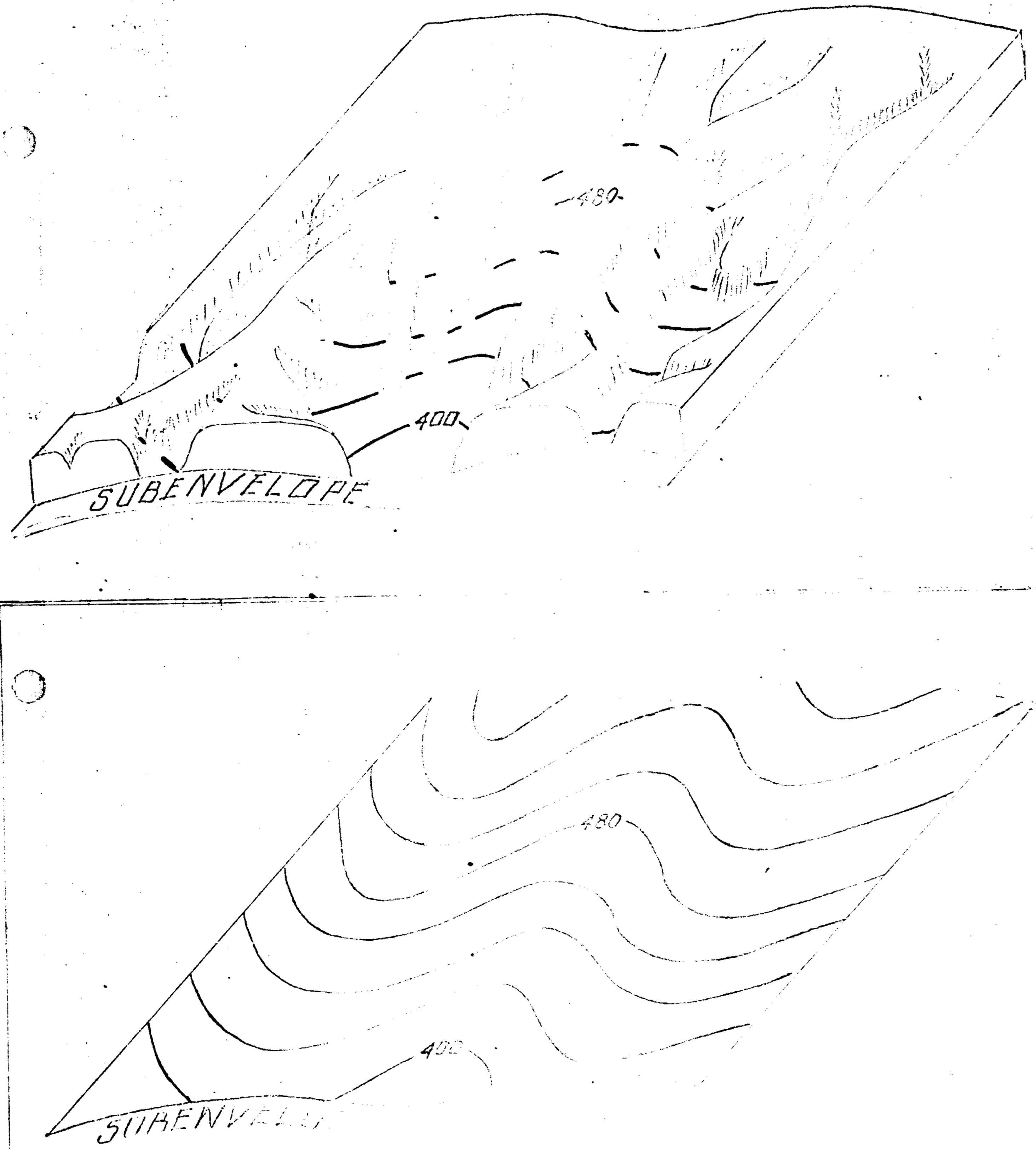


Figure 5[illegible]- The c[illegible] of a [illegible] envelope. The top figure shows [illegible] hypothetical topography as Figure 5[illegible] [illegible] segments of the subenvelope [illegible] stream [illegible]ters. The lower figure [illegible] "[illegible] away" leaving the [illegible].

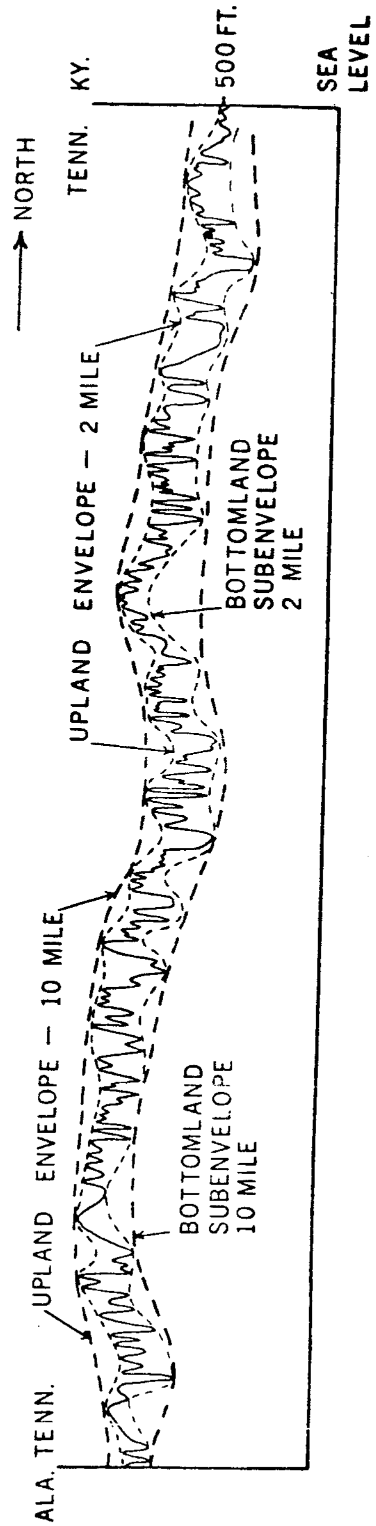


Figure 5c- Cross section showing the relationship of the land surface to envelopes and subenvelopes along the north-south profile of Figure 36

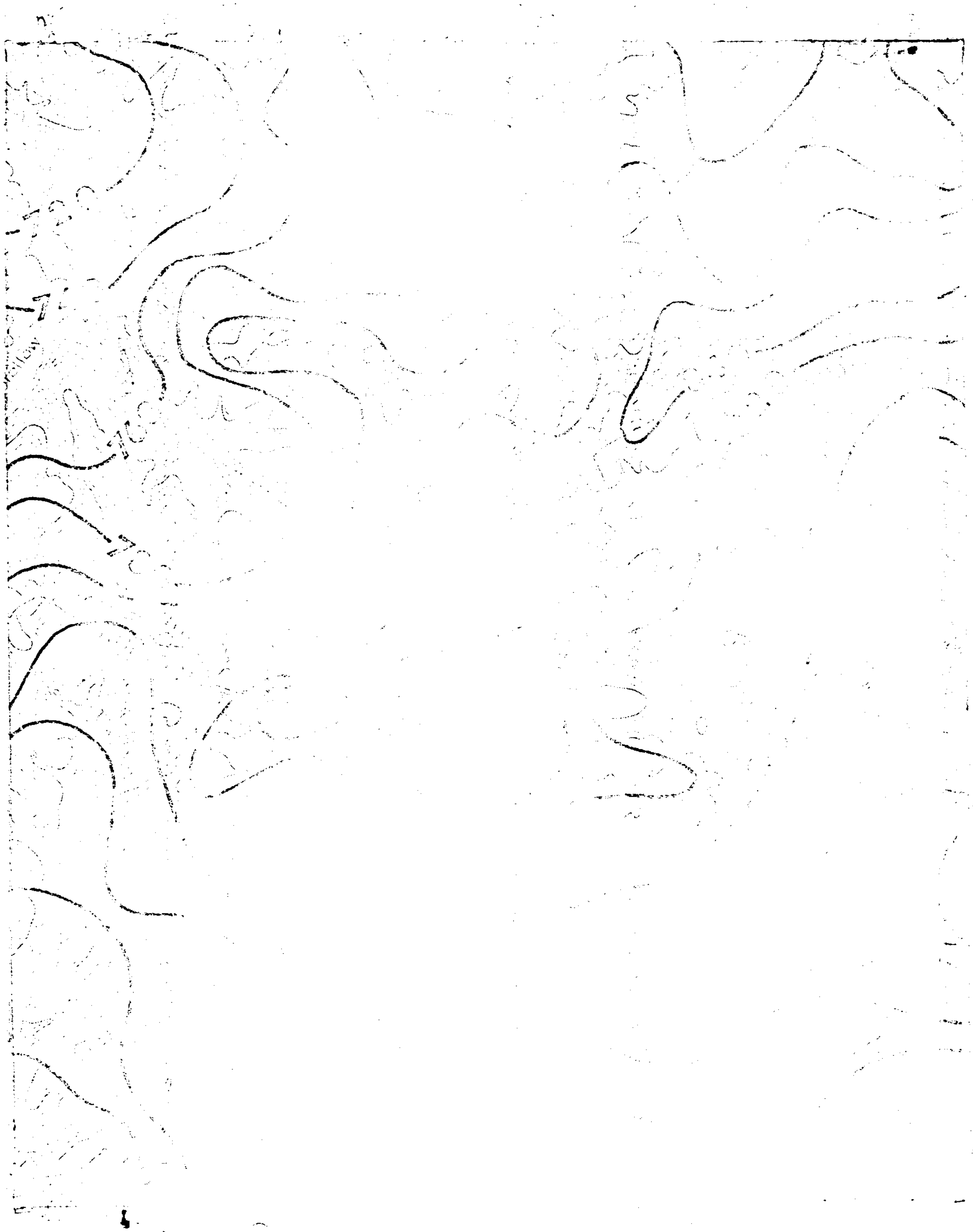
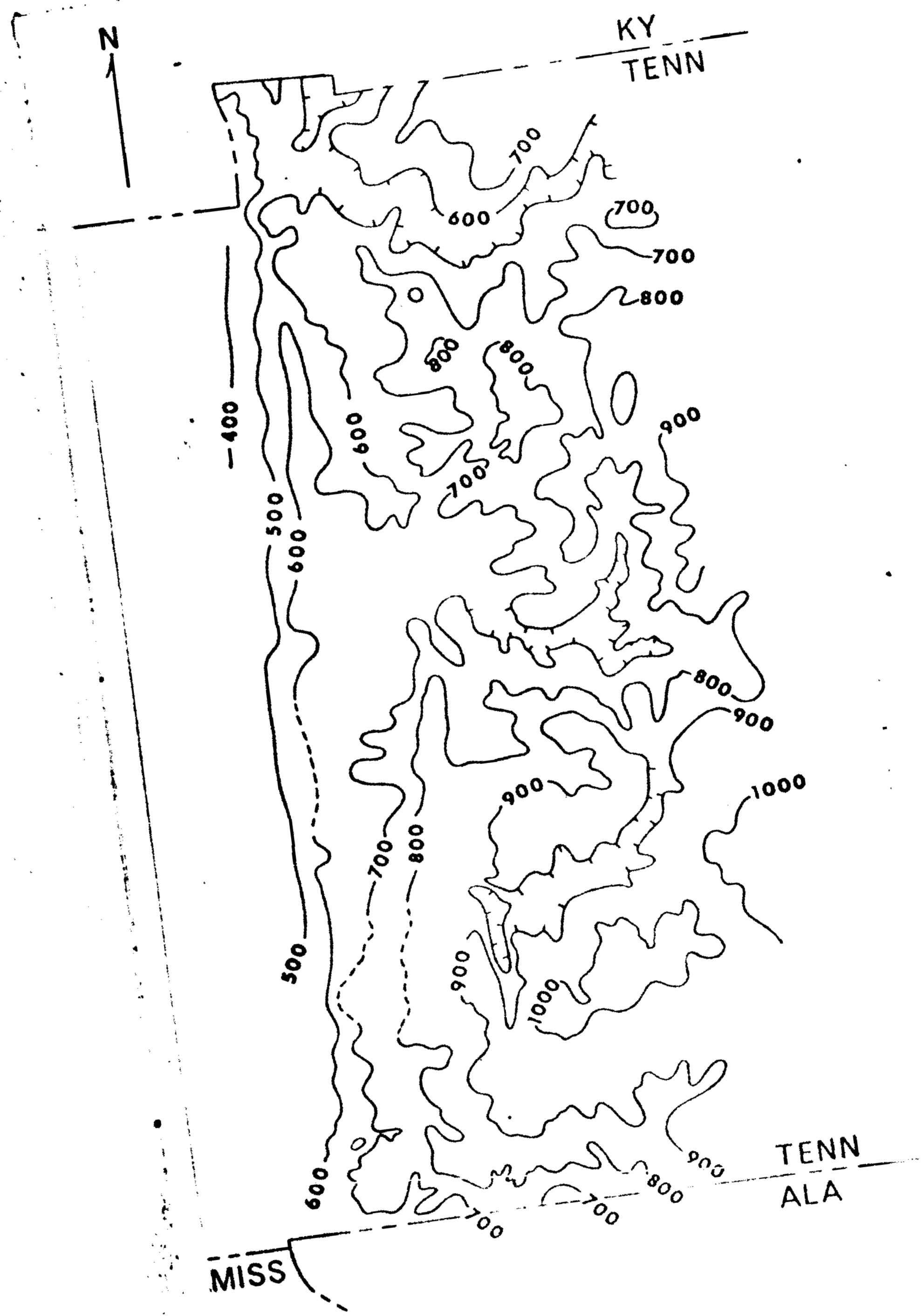


Figure 6- A 2,000-foot envelope drawn on a portion of the McEwen, Tennessee 7½-minute topographic quadrangle. Envelope contours are drawn with heavy lines.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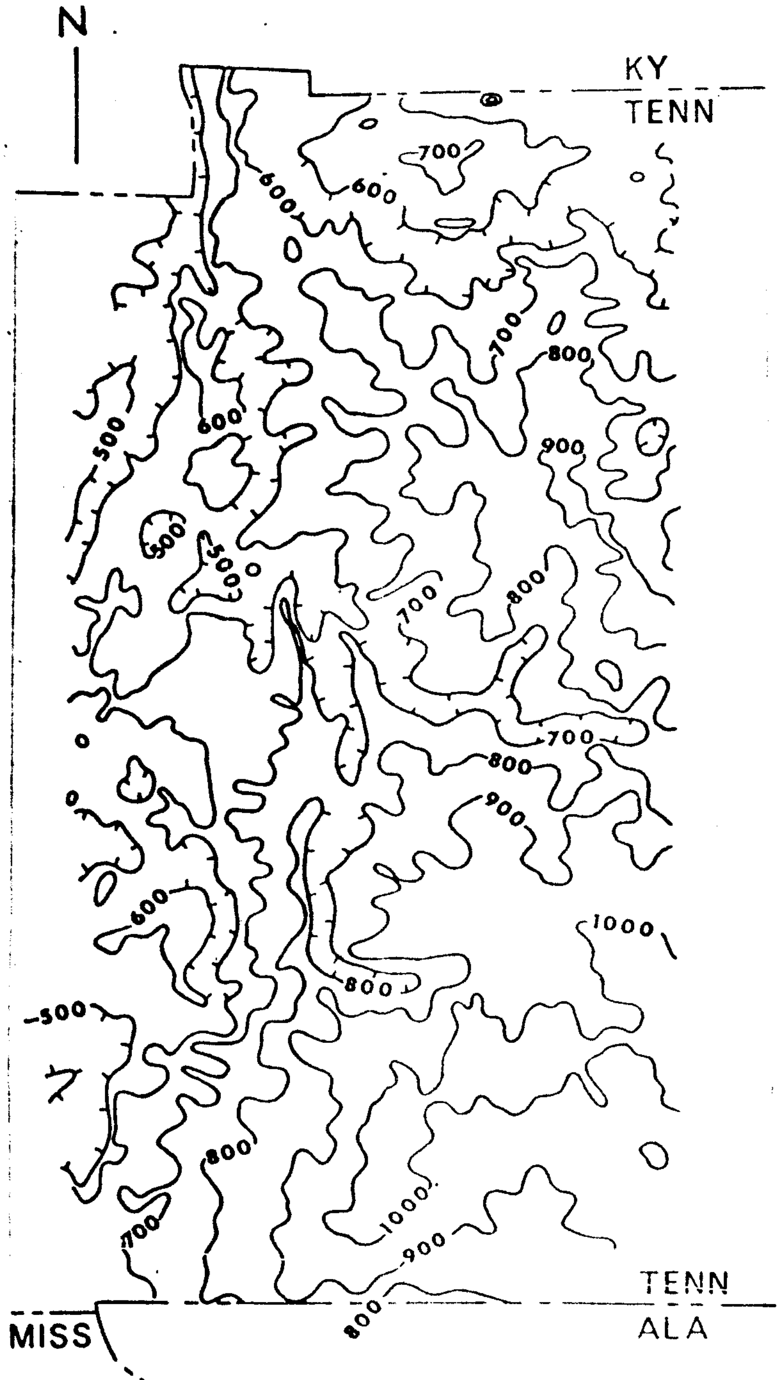
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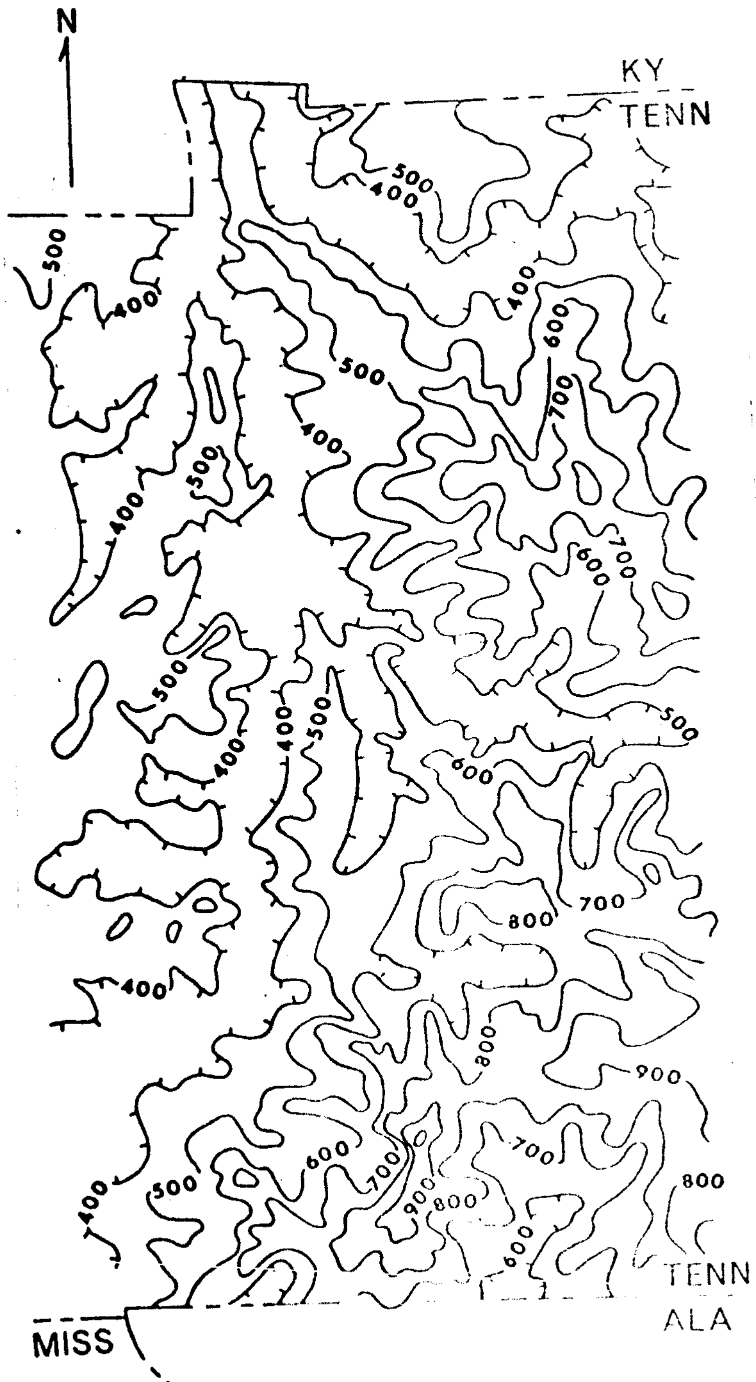
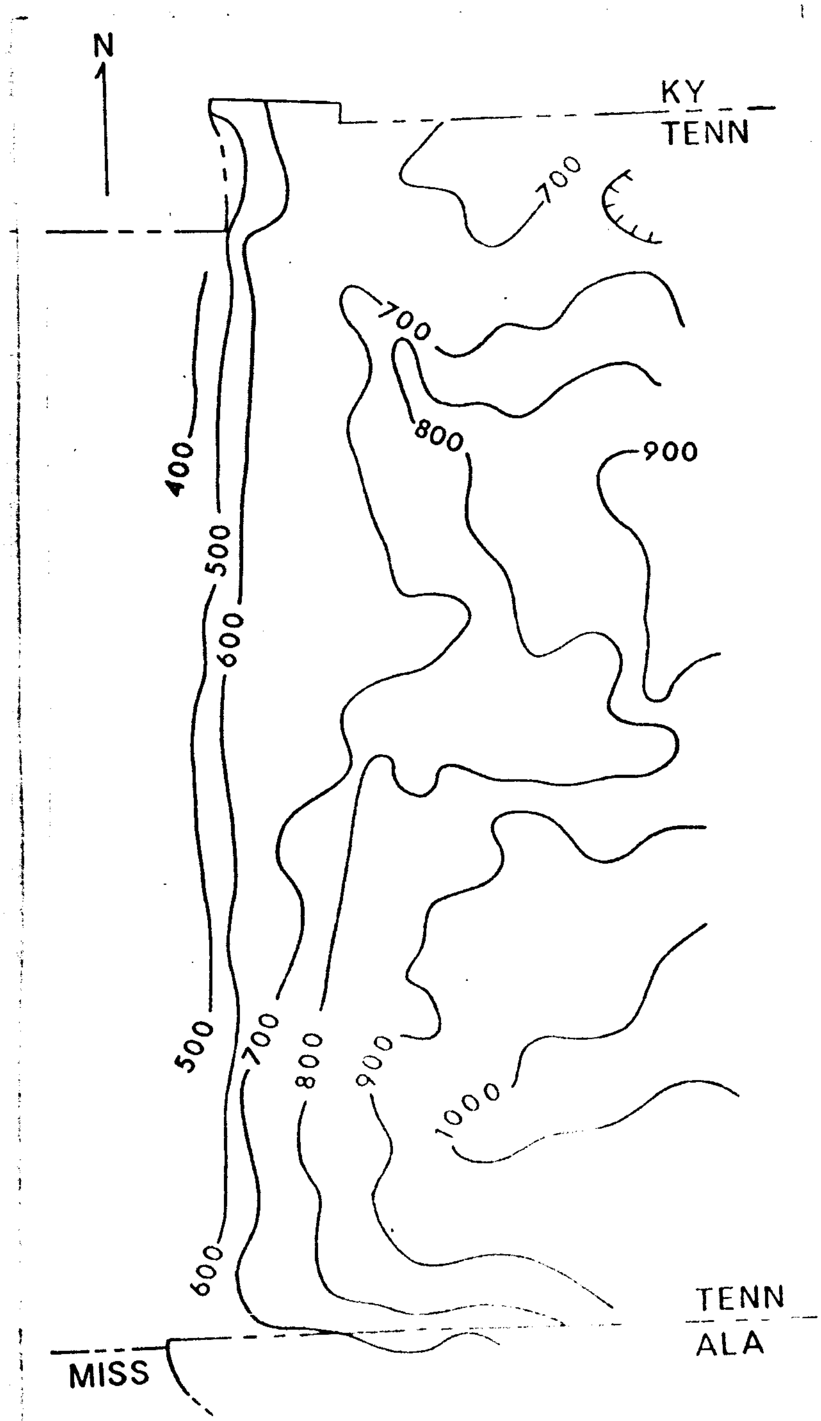


Figure 7. [illegible]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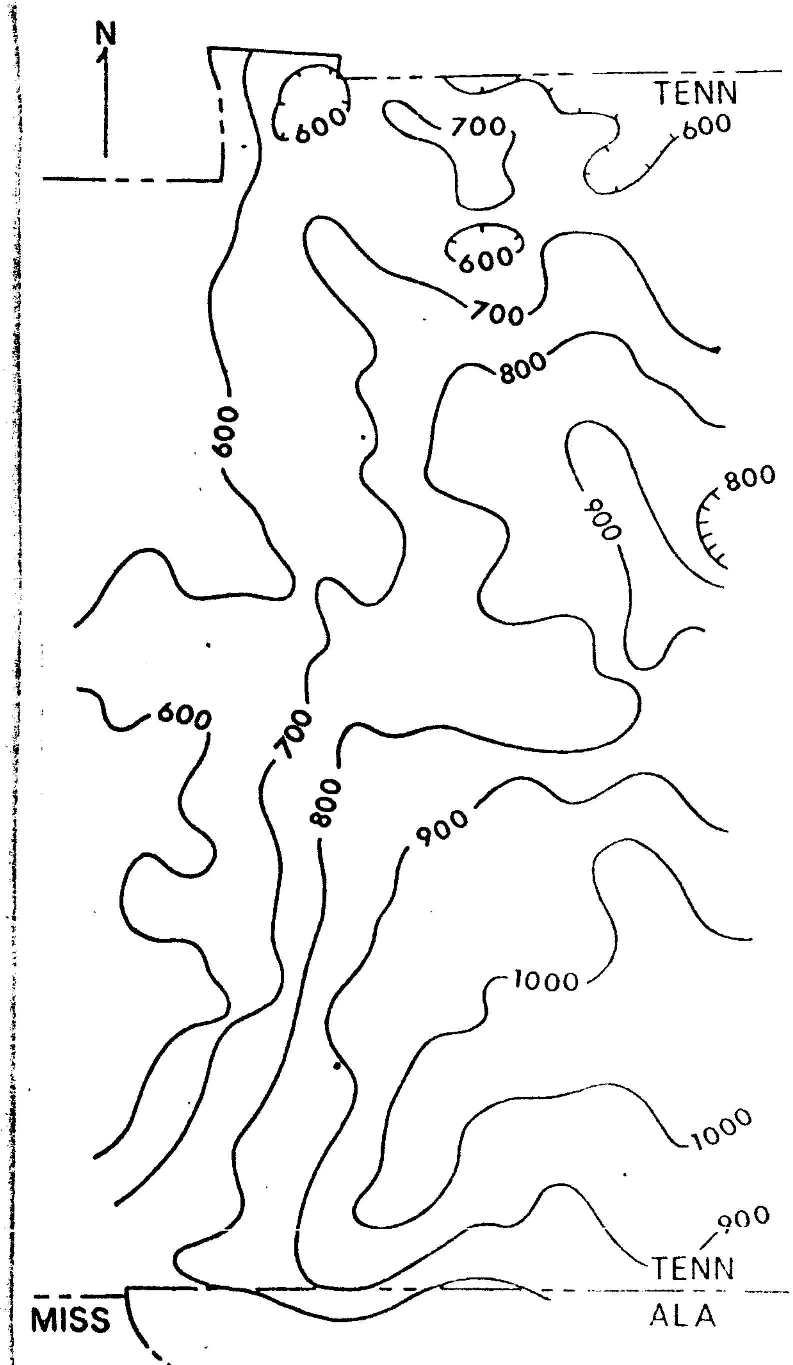

Figure 3b- Envelope [illegible]
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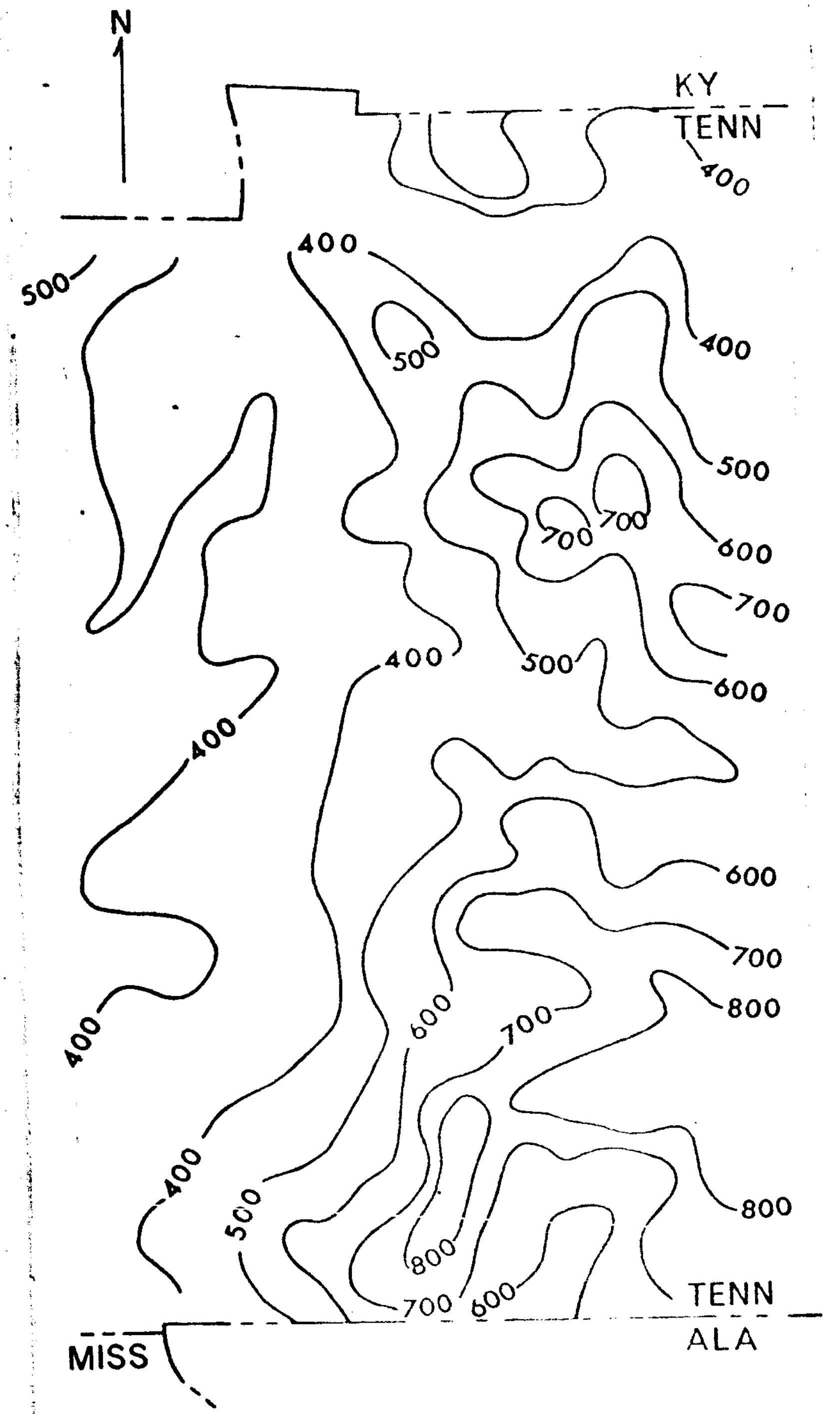
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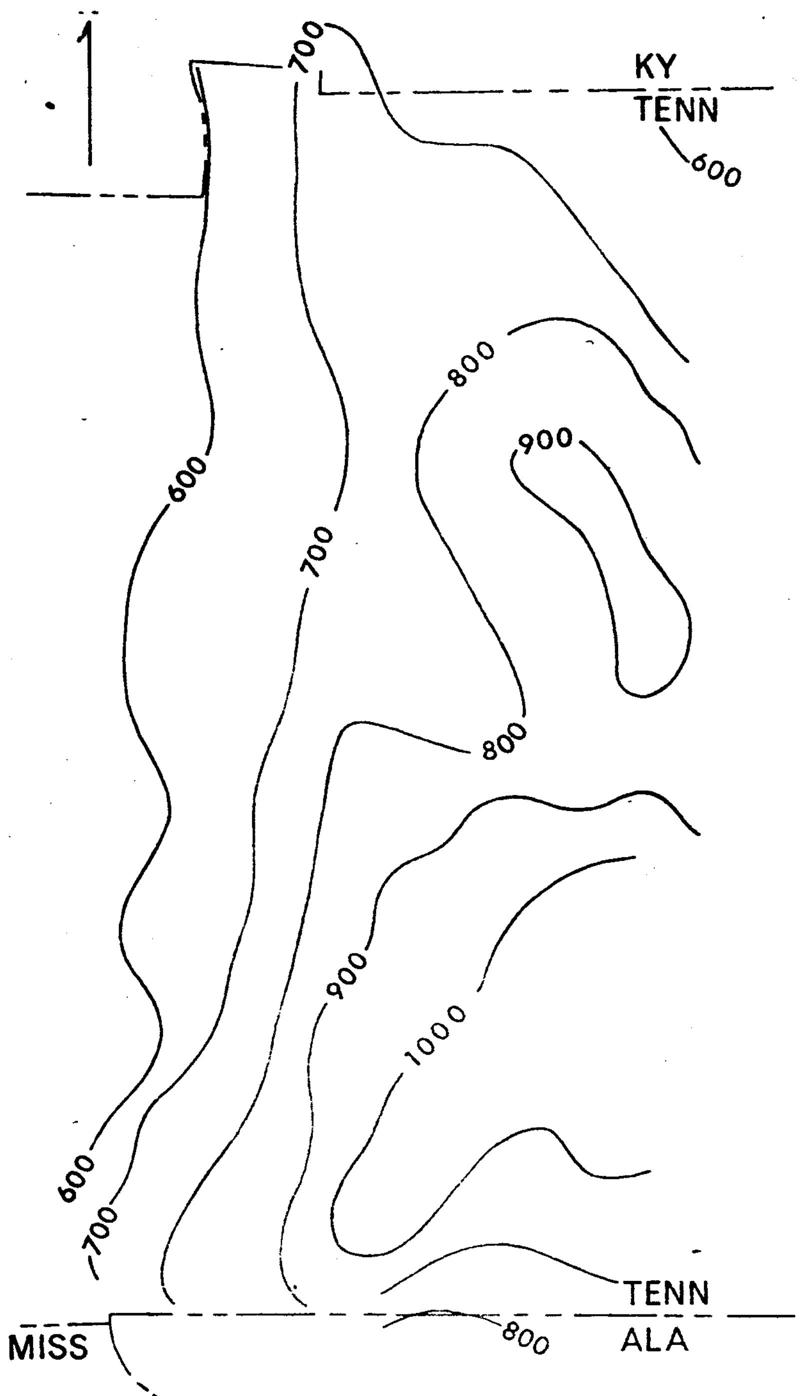

Figure 9- Envel[illegible] [illegible]ile spacing.

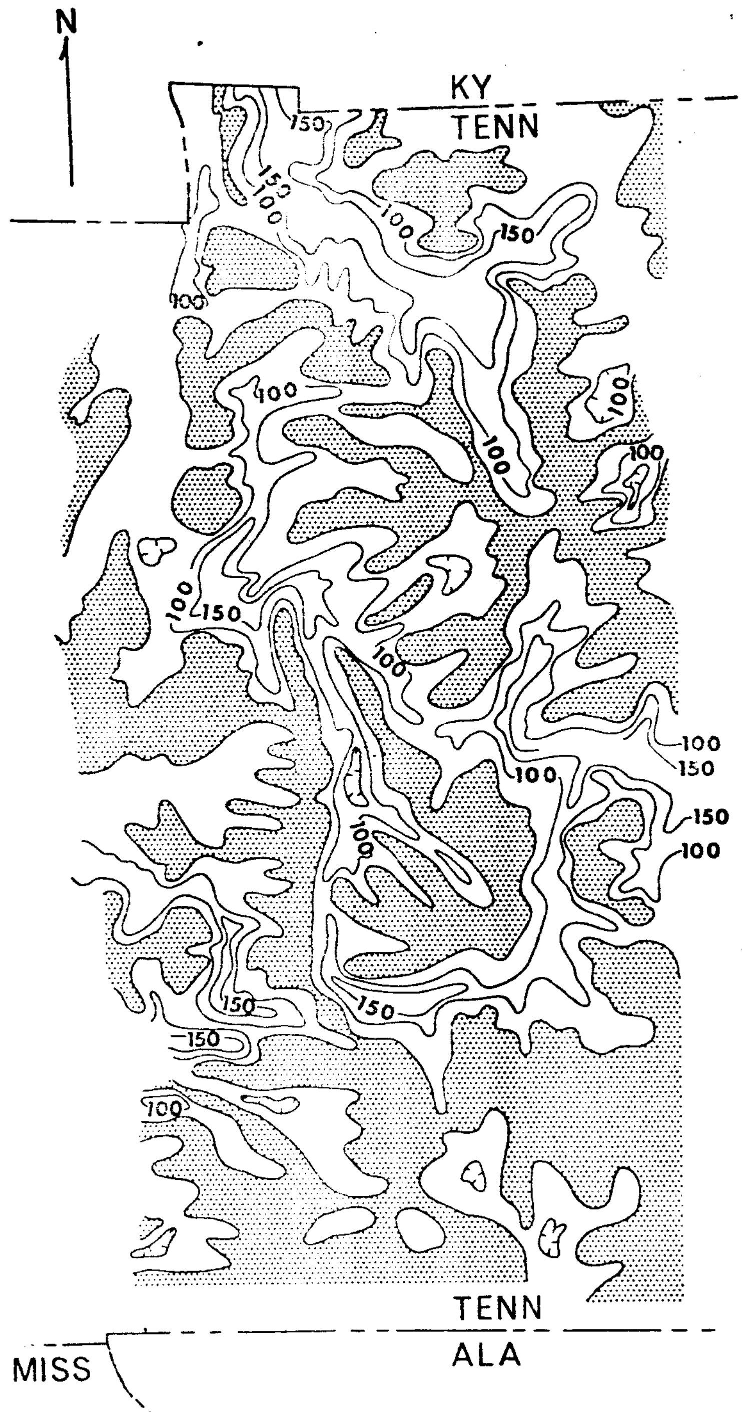

Figure 10- Pattern of local [illegible] of the upland surface toward [illegible]. This is probably an isopach map of [illegible] from beneath the upland by groundwater, or it may be the pattern of ancient valleys that developed the upland peneplain. Stippled pattern marks areas of slight [illegible], where the 2 and 6-mile envelopes nearly coincide.